McCOY

Density and Strength of Broken Stone Concrete

Civil Engineering

B. S.

1908

UNIVERSITY
OF
ILL. LIBRARY

UNIVERSITY OF ILLINOIS
LIBRARY

Class 1908 Book M13 Volume

My 08-15M

DENSITY AND STRENGTH OF BROKEN STONE CONCRETE

BY

MILTON HOWARD McCOY

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE, 1908

1908
M13

24 D 08 RITCHIE

UNIVERSITY OF ILLINOIS

June 1, 1908

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

MILTON HOWARD McCOY

ENTITLED DENSITY AND STRENGTH OF BROKEN-STONE CONCRETE

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

J. J. Richey
Instructor in Charge.

APPROVED: Ira O. Baker.

HEAD OF DEPARTMENT OF Civil Engineering

114893

Digitized by the Internet Archive
in 2013

http://archive.org/details/densitystrengtho00mcco

1408
M13

Proportioning Concrete.

Introduction

The principle underlying the correct proportioning of materials of concrete is that the mass when mixed and compacted shall have the greatest possible density. Before taking up the discussion of the best methods of proportioning it will be best to study first the general conditions which affect the density.

If perfect spheres of equal size are piled as compactly as possible, theoretically the voids will be 26% of the total volume. If now all the spaces of the mass be conceived to be filled with other spheres just large enough in diameter to touch the sides of the larger spheres and again the new spaces filled with smaller spheres until the voids become so small that water will not pass, the mass would be ideal in density. But it is found that all of these spheres can not be put in any such ideal form as just described. Instead the smaller ones get wedged between the larger ones forming new voids. It has been found that the amount of voids in a well compacted mass of equal sized marbles is not less than 44% of the total volume. By adding equal quantities of different sized marbles to a mixture it has been found that the percent of voids is about 65% at

The Rare Book & Manuscript Library
UIUC

the start but by shaking the mass and sluicing it the voids gradually reduce to 44% at which percent they remain constant.

With ordinary broken stones the above does not hold true except that on account of the stones' being more ragged they will not compact as closely and thus will contain more voids than those of perfect spherical shapes. The voids depend to some extent upon the roughness of the stone

When water is added to the dry cement and fine particles of the aggregate the small particles are separated from each other by the surface tension of the film of water, and it is no longer possible to obtain as dense a mixture as will be given by the dry cement and aggregate.

If cement is added to the mixture of the stone it evidently will take the place of some of the finer material already in the mixture, and therefore some of the fine material of the densest mixture must be removed to be replaced by the cement which is essential to the concrete.

The whole theory of a concrete mixture is well given by Feret as follows:-

"The problem of making the best concrete is thus reduced to the selection of a mixture of materials whose granulometric composition corresponds to

the maximum of density, since when this composition is known, absolute volumes of cement may be substituted for equal volumes of fine sand and vice versa so as to vary the strength as desired while the density remains the same."

Thus it is concluded that the density of concrete depends upon the roughness of the stone and sand, the relative sizes of stone and the amount of water used.

Two methods of determining the proportions to be used are given by Baker in his book on masonry. They are: 1. adjust the proportions so that the voids of the aggregate shall be filled with mortar and the voids of the sand with cement paste; and 2. fix the proportions with out regard to voids in the material. In the first method the densest mixture is supposed to be obtained by using stone of uniform size and a sand whose particles are all small enough to fit into its voids. But by theory and experiments it has been proved that this assumption is incorrect, because the smallest percentage of voids occurs in a mixture graded so that the voids of each size are filled with the largest particles which will enter them. The second method is inexact, because it does not take into account the amount of voids to be filled in the stone and sand.

The most practical method yet found for

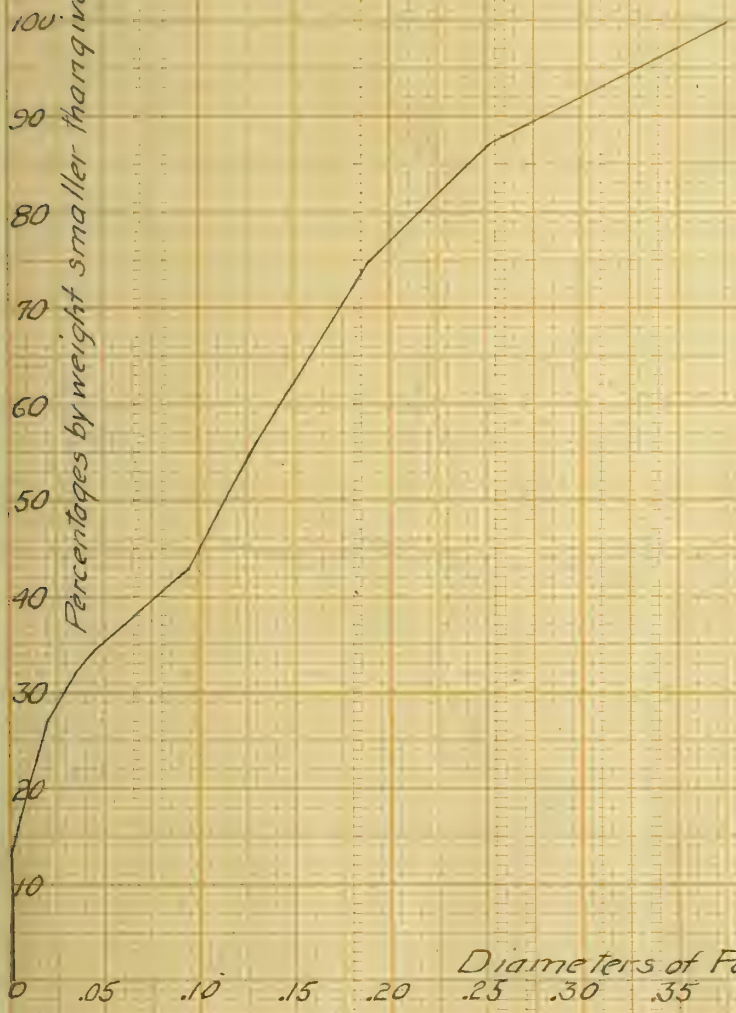
accurately determining the proper proportions of each size in the aggregate used for the densest mixture consists in making a mechanical analysis of the material. This analysis consists in separating the particles or grains of a sample of material into the various sizes of which it is composed so that the relative amounts of these sizes may be shown by a curve each of whose ordinates is the percentage by weight of the total sample which passes a sieve having holes of the diameter given by the distance of the ordinate from the origin of the curve. Thus on Plate I is shown the mechanical analysis curve for the limestone screenings used in the tests made by the writer, from which it may be seen that 40% of the mixture is smaller than 0.10 inch in diameter and about 13.3% of the screenings is smaller than the size caught on the smallest sieve.

The object of such a curve is to show graphically the sizes and relative proportions of the particles which will indicate what sized particles are needed to make the aggregate more nearly perfect. This enables the engineer to determine in what proportions to mix several aggregates to make the densest concrete.

Experiments performed by William B. Fuller at Little Falls N.J. in 1901 upon the relation of the

PLATE I

Mechanical Analysis Curve for Limestone Screenings.



U. S. F... S FORM ...

densely to transverse and compressive strength of concrete beams which were mixed in proportions by weight ranging from 1:0 to 1:6:10 showed that the strength of concrete varies with the percentage of cement contained in the set concrete, and also with the density of the concrete. Therefore if the percentage of cement is kept constant the densest concrete will be the strongest.

It was further shown that for any material used there was a certain combination of the sizes of the grains of the aggregate which when mixed with a given percentage of cement by weight gave the strongest concrete. A mechanical analysis curve of the mixture of sizes of particles of the aggregate which gave the best results approached a parabola with its begining at zero coordinates and passed through the intersection of the curve of the coarsest stone with the 100% line.

Among the conclusions that were made from similar tests made at Jerome Park, N.Y., in 1905 are:-*

1. "Aggregates in which particles have been special ly graded in sizes so as to give, when water and cement are added, an artifical mixture of greatest density, produce concrete of higher strength than mixtures of cement and natural material in similar proportions. The average increase in strength by artifical grading under the conditions

* See PROCEEDINGS OF AMERICAN SOCIETY OF CIVIL ENGINEERS Vol. XXXIII pages 222-298

of the tests was about 14 percent. Comparing the tests of strength of the concrete having different percentages of cement, it was found that for similar strength the best artificially graded aggregate would require about 12 percent less cement than like mixtures of natural materials.

2. The strength and density of concrete is affected but slightly, if at all, by decreasing the quantity of the medium size stone of the aggregate and increasing the quantity of the coarsest stone. An excess of stone of medium size, on the other hand, appreciably decreases the density and strength of the concrete.

3. The substitution of cement for fine sand does not affect the density of the mixture, but increases the strength, although in a slightly smaller ratio than the increase in the ratio of cement.

4. The correct proportioning of concrete for strength consists in finding, with any percentage of cement, a concrete mixture of maximum density, and increasing or decreasing the cement by substituting it for the fine particles in the sand or vice versa.

5. The best mixture of cement and aggregate has a mechanical analysis curve resembling a parabola, which is a combination of a curve

approaching an ellipse for the sand portion and a tangent straight line for the stone portion. The ellipse runs to a diameter of one tenth of the diameter of the maximum size stone and the stone from this point is uniformly graded."

A number of tests were made by the writer to verify some of the above conclusions. These tests were carried on in a similar manner to that used at Jerome Park. On account of a lack of sieve capacity and time the quantity of material that could be prepared was insufficient for performing as many tests as at first intended. Five mechanical analysis curves as shown on Plate II were chosen. One is the curve described in conclusion number five above, another is a true parabola, and the other three are broken line curves so chosen that the proportions of different sized stones and screenings would vary in each. A full description of these curves will be given later.

Description.

Materials

Cement Chicago A.A. portland cement was used in all of the tests. The specific gravity, fineness, and tensile strength are shown in Table I. As the cement came in two batches, two sets of tensile

Mechanical Analysis Curves Used in Tests.

Note:- For description of curves see p. 14.

Material used was broken stone and cement.

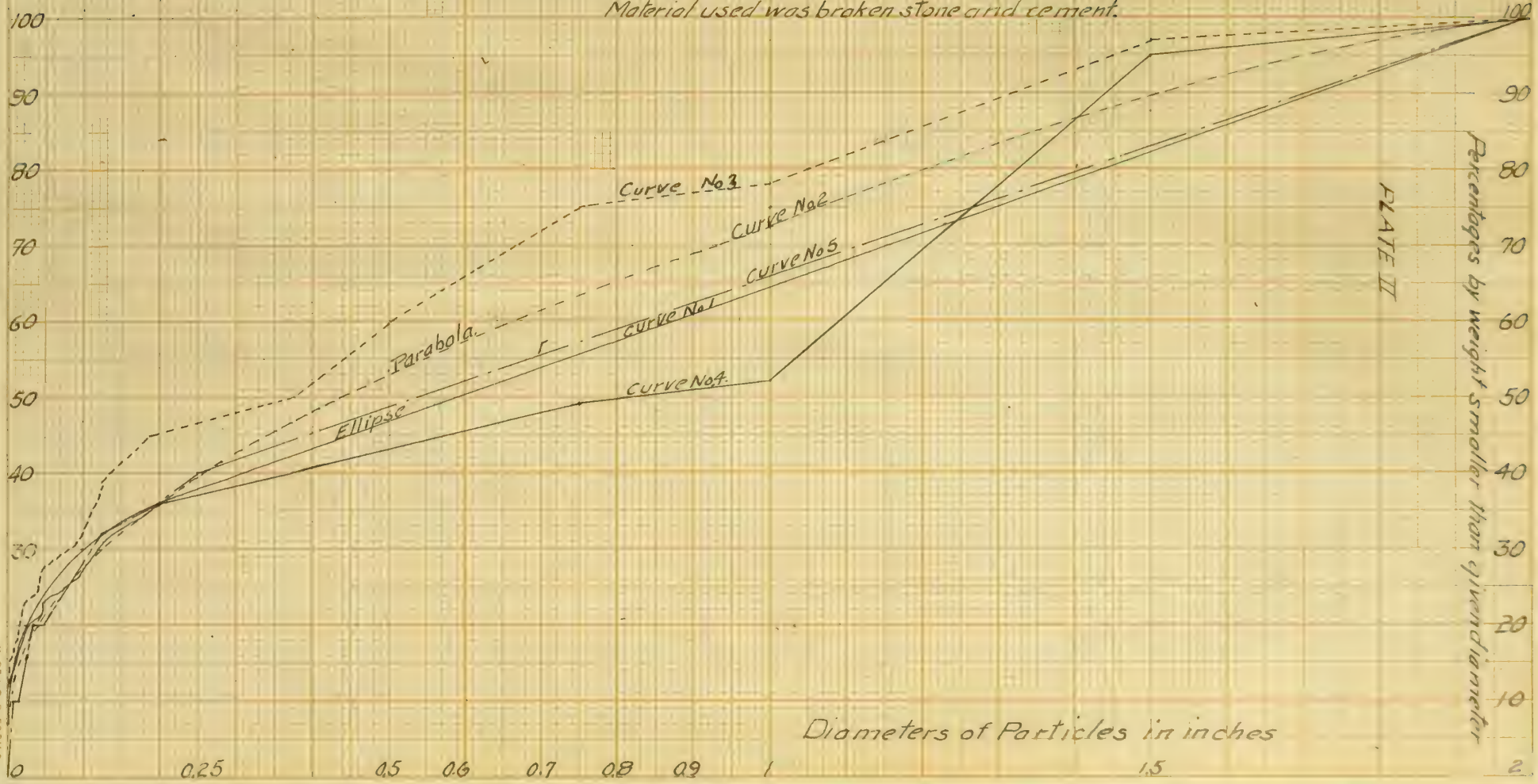


PLATE II

U. OF I. S. TORVT.

tests were made in each of which there were five briquettes tested at the age of 28 days. The results were close enough together to assume that the strength was the same for both batches.

TABLE I.

Kind of Cement	FINENESS				TENSILE TEST				Remarks.
	Total Used	Am't retained		% retained	Batch No.	Briquette No.	Breaking Load, lbs.	Age days	
		Siere No.	Wt. Units						
Chicago A.A. Portland	1000gr.	74	115	11.5%	1	1	880	28	Specific gravity was 3.12
		100	19.5	1.95%		2	905	"	
		200	167.0	16.7%		3	900	"	
		Pan	802.1	80.2%		4	890	"	
		Total		100.0%		5	870	"	
					2	1	860	"	
						2	880	"	
						3	880		
						4	850	"	
						5	880	"	
						Average	880		

Aggregate. Broken Kankakee Lime Stone was the only aggregate used. The stone came from the crushers at Kankakee after having been run through the revolving screens to remove stones of greater diameter than two inches, which was the maximum size used, and to separate the screenings, which were handled separately from the coarser stone.

For density tests the stone and screenings were separated in the laboratory by nineteen sieves ranging in size from 2 inch openings to No. 200 mesh in which the openings are

concrete. By using different quantities of the sizes separately these sieves it was possible to obtain any number of different proportions.

Stone The stone was a gray limestone with a specific gravity of 2.61 which was an average of eight samples taken from different parts of the quarry. The average absorption for the same samples was 3.04 pounds of water per cubic foot of stone.

Sieves Large sieves about two feet square were used for screening the aggregate from two inches down to and including $\frac{3}{23}$ inch in diameter. The smaller sizes were separated in a nest of sieves of the standard size. This nest was rocked in a machine which was run by electric power.

The larger sieves rested in a frame, five being put in at once. The frame rested upon a pair of rockers consisting of two inch oak plank, sawed with angles so that the motion was a combined jar and slide. The frame and sieves may be seen in Plate II.

This form of frame and sieves worked fairly well if the same amount of stone was put in each time and rocked the same number of minutes so as to get uniformity of screening. The commercial numbers and nominal

sizes are given in table II

TABLE II

Nominal size of sieve in inches	Diameters passing sieve in inches	Nominal size of sieve in inches	Diameters passing sieve in inches	Commercial no. of sieve	Diameters passing sieve in inches	Commercial no. of sieve	Diameters passing sieve in inches
2.0	2.0	0.25	0.25	16	0.045	100	0.0058
1.5	1.5	0.187	0.187	20	0.034	200	0.0027
1.0	1.0	0.125	0.125	30	0.020		
0.75	0.75	0.0936	0.0936	40	0.016		
0.50	0.50			60	0.0115		
0.375	0.375			74	0.0071		

Volumetric Tests

Method and Apparatus for Determing Density. The tests of density are termed volumetric tests. Mixes were made for each aggregate to be used in the tests, each containing 10% cement to the total weight of the dry material, and mixed with water to the same medium wet consistency and the resulting volumes thus obtained from exactly the same total weight of dry materials were compared.

The apparatus consisted of a wrought iron cylinder 8.155 inches inside diameter and 13.06 inches deep with a removable bottom, an iron rammer to compact the

PLATE III

APPARATUS USED IN VOLUMETRIC TESTS
AND IN MAKING BEAMS.

mixture in the cylinder, a mixing pan, a trowel, a rubber scraper to clean the mixing pan, a bucket and dipper for water, a syringe to remove surplus water, a scale to measure the distance from the top of the cylinder to the top of the compact mixture, and platform scales for weighing.

Weighing All materials were proportioned by dry weight. The stone and screenings were all deposited in bins and pans, each being labeled to show the size. The schedule of weights of the aggregate was made up so that each weight included the weight of all the finer materials. In this method of weighing the poise was reset for each added size of material which was placed in the pan on top of the preceding one. This gave a total weight equal to that calculated in the schedule. The cement was weighed last and placed on top of all the other materials.

Mixing The materials were mixed dry with a large trowel by turning the material until it was of a uniform color. The mass was then placed in a mound with a hollow center and water poured on, after which it was turned until it was thoroughly

mixed.

On account of the variation in sizes of the particles of the aggregate in different volumetric mixtures it was impracticable to use the same proportion of water for each; since the mixtures containing the largest quantities of fine material required the largest percentage of water to make concrete of the same consistency.

Water was therefore added until a soft mushy mixture which would not quite allow the mortar to run from the stones was obtained. A pail of water with a dipper was first weighed; then the required amount of water was taken out and the remainder was again weighed, thus giving a means of obtaining the exact net weight of water used.

Ramming The mixed concrete was introduced into the cylinder and rammed in two inch layers. This was necessary because the cylinder was small and the friction of the sides would prevent the material from settling if more than two inches were put in at once. The rammer used was a cast iron block about three inches square with an upright handle.

Removing Surplus Water. When the mixture was rammed the surplus water and mortar came to the

top and the water after some time formed on a clear layer on the surface. This was removed by a syringe and the weight removed was deducted from the weight of water used in the mix in order to determine the weight contained in the mixture set.

Final Weighing. The mixing tray together with the tools was weighed and the quantity of material adhering to them was thus found it being the difference between this weight and the weight of the clean tray and tools. The weight of the portion of the mix adhering was deducted from the actual weight of materials weighed out. It was assumed that material adhering passed the no. 74 sieve and that the proportions of stone dust, cement, and water were same as those in the total mixture.

Measurement. After the surplus water had been removed care was taken that the surface of the mixture should be level and that no stone should project above the surface. Then by means of a steel scale the average distance from the top of the cylinder to the top of the concrete was obtained. The test was then complete and ready for computations; the record having been entered upon a form similar to that used by Fuller, as shown in Table III. The concrete was

TABLE III

Volumetric Tests.

	1	2	3	4	5
1 No					
2 Date	Feb. 22	Feb 24	Feb 29	Mar 7	Mar. 25
3 Nominal Mix.	$1:2^5:7^5$	$1:2^5:7^5$	$1:3^5:5^5$	$1:2^5:7^5$	$1:2^7:6^3$
4 Kind of Cement Chicago A.A.	C.A.A.	C.A.A.	C.A.A.	C.A.A.	C.A.A.
5 Weight	1500 gr.	1500 gr.	1500 gr	1500 gr.	1500 gr.
6 Wt of Aggregate finer than 0.0071	573.8	399.6	1145.	817	0
7 " " " coarser " "	12926.2	13100.4	12355	12683	13500
8 " " Vessel + Water (1)	6810	5440	4320	4930	3080
9 " " " " (2)	5610	4220	2930	3730	1850
10 " " Water used.	1200	1220	1390	1200	1230
11 Total Wt. mixed	16200	16220	16390	16200	16230
12 Wt of Tray + Tools (2)	11640	11640	11550	11520	11660
13 " " " " (1)	11590	11600	11520	11500	11610
14 " " Mix adhering	50	40	30	20	50
15 " " Syringe + Water	80	80	60	65	136
16 " " "	70	60	60	65	70
17 " " Free Water.	10	20	0	0	66
18 Net Mix set = 11-14-17	16140	16160	16360	16,180	16,124
19 Water left on Tray $\frac{10\times14}{5+6+10}$	18.32	15.68	10.33	6.83	22.52
20 Net Water set 10-17-19	1171.68	1184.32	1369.66	1193.17	1141.48
21 Net Cement set 5- $\frac{5\times14}{5+6+10}$	1477.09	1480.74	1488.9	1491.17	1472.5
22 " Aggregate finer than .0071 = $6\times\frac{6\times14}{5+6+10}$	565.0	394.15	1136.48	812.35	0
23 " " coarser " "	12926.2	13100.4	12355	12683	13500
24 Depth of Concrete in Cylinder in inches	7.837	7.79	8.062	7.98	7.875
25 Vol. of " " " " cubic feet.	.2368	.2344	.2426	.240	.238
26 Net Water per cubic ft. as mixed $\frac{10}{25}$	5067.5	5199	5730	5000	5157
27 " " " " " " set $\frac{20}{25}$	4949	5050	5640	4970	4786
28 " Cement " " " " " $\frac{21}{25}$	6231	6310	6130	6220	6187
29 " Aggregate " " " " $\frac{22+23}{25}$	56962	57490	55,520	56180	56,720
30 Abos. Vol. Water per cu.ft as set $\frac{27}{\text{No. gr. in 1 cu.ft.}}$	.174	.178	.199	.175	.169
31 " " Cement " " " " $\frac{28}{\text{No. gr. in 1 cu.ft.}}$	.070	.071	.0694	.07	.070
32 " " Aggreg. " " " " $\frac{29}{\text{No gr in 1 cu.ft.}}$	.77	.78	.752	.761	.768
33 Total abs. vol. 30 + 31 + 32.	1.014	1.028	1.01	1.005	1.008
34 Temp. of Water	16°	17°	16°	16°	17°
35 Time of mixing after wetting	5 min.	5 min.	5 min	5 min.	5 min.

Remarks. The numbers in the equation after any item correspond to the numbers of other items from which that item is obtained

TABLE III cont.

Curve	Reference No	Weight in Pounds of Material in 1 cu. ft of concrete as set							Calculated Volume in 1 cu. ft. of Material as set in 1 cu. ft.					Vol. voids in 1 cu. ft.
		Cement	Aggregate	Total Dry mixed	Water	Totals. Set	Minimum Possible	Maximum Possible	Cement	Aggregate	Total Dry.	Water	Total	
														Cu. ft.
Ellipse	1	137	125.	138.7	10.9	149.6	139.8	148.7	.070	.77	.84	.174	1.01	.16
Parabola	2	139	126.1	140.	11.1	151.1	141.1	149.4	.071	.78	.85	.178	1.028	.15
Broken Line 1	3	135	122.2	135.7	12.4	148.1	136.8	147.0	.0694	.752	.819	.199	1.018	.181
" " 2	4	137	123.8	137.5	10.9	148.4	138.6	148.1	.0704	.761	.83	.175	1.00	.17
" " 3	5	136	125	138.6	10.5	149.1	139.7	148.7	.07	.769	.839	.169	1.008	.161

Note The Min. Possible = Wt. cement x.08 + Wt. of Total Dry Mixed
The Max Possible = Wt. cement + Vol. of Voids in 1 cu. ft. x 62.4
Assume 8% of the water for chemical combination.

thrown away and the tools were cleaned and kept ready for another test.

Recording and Computing Data. Table III shows the form used for recording which was so arranged that the weight could be entered in the laboratory. The absolute volumes given on the table represent simply the ratios of the actual volume of each ingredient to the total volume of concrete and are figures by which the different mixes are compared.

Mechanical Analysis Curves Used. The curves all start upon and are tangent to the vertical zero axis of percentages at 7% which was the origin of the Jerome Park curves. It was necessary to raise the origin of the curves because the mechanical analysis included the total aggregate and the cement.

One curve is a true parabola which has its vertex at the origin given above and running as shown on Plate II. Another curve which will be called the ellipse curve, starts as seen on Plate at a point of 0 and 7% coordinates and is a true ellipse up to a point corresponding to one tenth of the two inch maximum size stone used, and from there it runs as a tangent to the ordinate of maximum diameter, intersecting this on the 100% abscissa.

The equations of the parabola and ellipse of

the description given above are:-

Parabola $y = 7 + 100\sqrt{kx}$

Ellipse $(y-7)^2 = \frac{b^2}{a^2}(2ax - x^2)$

a & b being the horizontal and vertical axes respectively. As the time available for these tests was limited, tests were not made to determine the constants for the equation of the best ellipse curve for the broken stone used, but the constants found in the Jerome Park tests for broken stone were used. These constants were:- $b = 27.4 + 2.2D$ and $a = .035 + .014D$. Where D is the diameter of the maximum sized stone.

Three other curves consisting of broken straight lines were chosen so as to give a wide variation in the combination of sizes to determine what effect such variations would have upon the strength and density of the concrete. Ten percent of cement by weight of the total dry material was used in all the mixtures.

Beam Tests.

Two beams were made for each curve. The proportions used were the same as those used in the volumetric tests. Besides the beams, which were six inches square and six feet long, two six inch cubes for compression tests were made for each curve, all being made

from the same mix. The results are given in Table IV.

Making Beams. The weight of each diameter of material and cement was calculated by direct proportion from the percentage or mechanical analysis curve and the approximate quanity of water to be used was estimated from that used in the volumetric test made with the material of the same mechanical analysis as the same maximum sized stone was used in all, and the specific gravity remained the same; the quanity in each case remained practically the same as in the volumetric tests. The pan for receiving the material was placed on the scales and beginning with the finest the different size's of the aggregate were weighed out and piled ready to mix.

Mixing. The dry material was dumped upon a mixing platform consisting of a steel plate five by eight feet, and thoroughly mixed by turning with a shovel. Then the mixture was formed into circular pile and the aproximate quanity of water was turned into it. The material was then turned wet until it was uniform throughout. The mixture when ready for the forms was soft and mushy, but the

TABLE IV

Transverse Strength & Compressive Strength of Broken Stone Concrete With Differently Graded Aggregates

Kankakee Limestone —. Chicago A.A. Cement.

Curve.	Curve No.	Proportion by Weight	Percentage of cement to total Dry Mixture	Max. size stone in in.	Transverse Strength					Compressive Strength		Remarks. Character of the transverse fracture.
					Age in days	No of beaks	Pounds per square inch			Age of tube days	Pounds per sq. in.	
							Max.	Min.	Average			
Ellipse	1	1:2½:7½	10	2	28	2	286	250	268	28	2680	Voids small. Some stones
"	1	"	10	2	"	"	354	320	337	"	2740	broken through.
Parabola	2	1:2½:7½	10	2	"	"	367	358	362.5	"	3220	No voids visible
"	2	"	10	2	"	"	465	450	457.5	"	3160	" "
Broken Line 1	3	1:3½:5½	10	2	"	"	323	250	286.5	"	2180	Some stones broken through
" "	3	"	10	2	"	"	328	272	300.	"	1790	some voids.
Broken Line 2	4	1:2½:7½	10	2	"	"	293	225	259	"	1850	Stones broken through.
" " "	4	"	10	2	"	"	314	222	268	"	2310	" " "
" " 3	5	1:2⅞:6⅜	10	2	"	"	410	239	320.5	"	1730	Voids not visible
" " 3	5	"	10	2	"	"	398	247	322.5	"	1820	No stones broken through.

TABLE V

PERCENTAGES OF BROKEN STONE AND CEMENT USED FOR DENSITY TESTS, BEAMS & CUBES.

Size of Particles inches	Curve No 1 %	Curve No 2 %	Curve No 3 %	Curve No 4 %	Curve No 5 %
0 - .0027	3.110	2.390	6.310	3.984	0
.0027-.0058	.271	- .009	1.150	.864	0
.0058-.0071	.445	.265	.790	.594	0
.0071-.0115	1.675	1.395	.330	.261	0
.0115-.016	1.510	1.280	1.550	1.164	3.00
.016-.02	1.150	.970	1.550	1.164	4.00
.02-.034	3.150	2.820	2.330	1.174	3.00
.034-.045	2.270	1.830	.740	.555	.00
.045-.093	6.010	6.100	3.560	2.570	7.200
.093-.125	2.790	3.200	4.580	3.435	4.800
.125-.1875	3.710	5.220	6.700	5.025	4.000
.1875-.25	2.050	4.410	6.280	4.710	4.000
.25-.375	4.418	7.660	4.930	3.696	4.280
.375-.5	4.418	5.960	10.200	3.140	4.280
.5-.75	8.836	10.460	15.000	6.000	8.570
.75-1.0	8.836	8.810	3.000	3.000	8.570
1.0-1.5	17.673	14.780	19.000	43.000	17.140
1.5-2.0	17.672	12.450	3.000	5.000	17.140
Cement	10.000	10.000	10.000	10.000	10.000
Total	100.	100.	100.	100.	100.

Note. All the percentages down to the last item are for broken stone and screening alone.

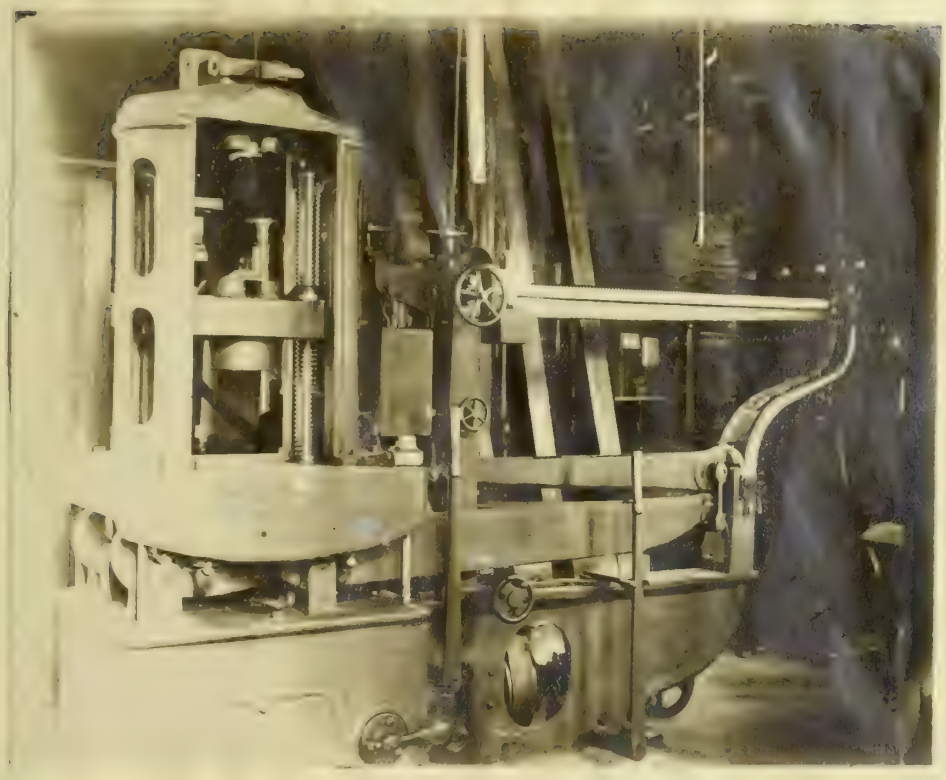
mixer would not quite run away from the stones.

Placing in forms. The forms for the beams were made of two inch hemlock each having three clamps. The inside dimensions were 6"x6"x6'-6". The concrete was shoveled into them in two inch layers and tamped with an iron tamper. The blade of a trowel was thrust down by each face of the forms for every two or three inches of depth to insure a smooth surface. When the form was full the tops of the beams were smoothed off by means of a trowel.

At the end of seven days the forms were removed from the beams. Water was poured on the beams each day from the time of making till they were broken.

Breaking of Beams. The machine for breaking the beams was a two screw, 100,000 pound machine made by Riehle Brothers of Philadelphia. It is shown on Plate IV. In order to bring the load upon the beam very slowly a six by six inch wooden beam was first laid upon the table of the machine and the concrete beam supported upon it. The bending of the wooden beam caused the loading to be applied more slowly than if the concrete beam had been supported directly upon the iron table of the machine.

PLATE IV



RIEHLE TESTING MACHINE

Each beam was first broken by loading at the third points of a sixty inch span. Then a second break was made in the longest piece left using a span of thirty inches and loading at the third points.

Each beam was carefully measured and found to be six inches square. The record of all the beams is given in Table IV.

Compression Tests.

The six inch cubes for compression tests were made in iron forms at the same time that the beams were made. At the age of seven days they were taken out and weighed. They were then put in sand which was kept wet until they were taken out to be capped with plaster of paris one day before they were broken at the age of 28 days.

The plaster of paris was used to make an even bearing surface in order that the pressure would be the same over the entire surface. A thin layer of the plaster of paris paste was first spread on a piece of plate glass. Then the cube was placed on this paste and jarred slightly to insure good bearing on the paste. Another layer

of paste was placed on the top of the cube and another glass was placed on top to make a smooth level curing surface. After 24 hours the glass plates were removed and the cube was ready to test. The results are given in Table II

Conclusion.

A study of the relation between the results of the above tests and the conclusions stated at the beginning brings out the following verifications and conclusions:-

The densest concrete is the strongest in both transverse and compressive strength which verifies the conclusion 1 on page 5. The ratio of the increase in strength to the increase in density can not be determined with the small number of tests made.

Conclusion 2 on page 6 is verified. The decrease in medium sized stone in curve 4 as compared to that used for curves 1 and 2, which are the best, affects the density and strength of the mixture by only a small percent. It is also seen that the strength and density of the mixture from curve 3 which has a large quanity of medium sized stone as compared to curves 1 and 2 is much

less than for any other mixture made in the test.

Conclusion 5 on page 6 is not verified. "The densest and strongest concrete was produced from curve 2 which is the true parabola. This does not disprove, however, the conclusion that curve 1, which is the ellipse would not give the densest and strongest if the true constants for the equation had been found by actual tests upon the broken stone used instead of using those found in the Jerome Park tests. Moreover the number of tests made was not large enough to insure a fair average of the results.

The maximum size stone used in the tests was too large for the forms. The large stones would become bound on one another when the mixture was tamped in the forms, thus making the compacting of the mass difficult and preventing the densest concrete being made. This difficulty would have been avoided if smaller stones had been used for the six inch forms.

The results would probably have been more accurate and valuable had an average of two volumetric tests instead of one been taken for each curve.

In referring to Table IV it is seen that a fairly uniform ratio exists between the

transverse and compressive strengths of the mixtures. This being true it is suggested that in future tests no beams be made, but instead only cubes for compressive tests. This would allow more tests being made with the same expenditure of time and material and thereby give a better average of results.

UNIVERSITY OF ILLINOIS-URBANA
3 0112 086764534